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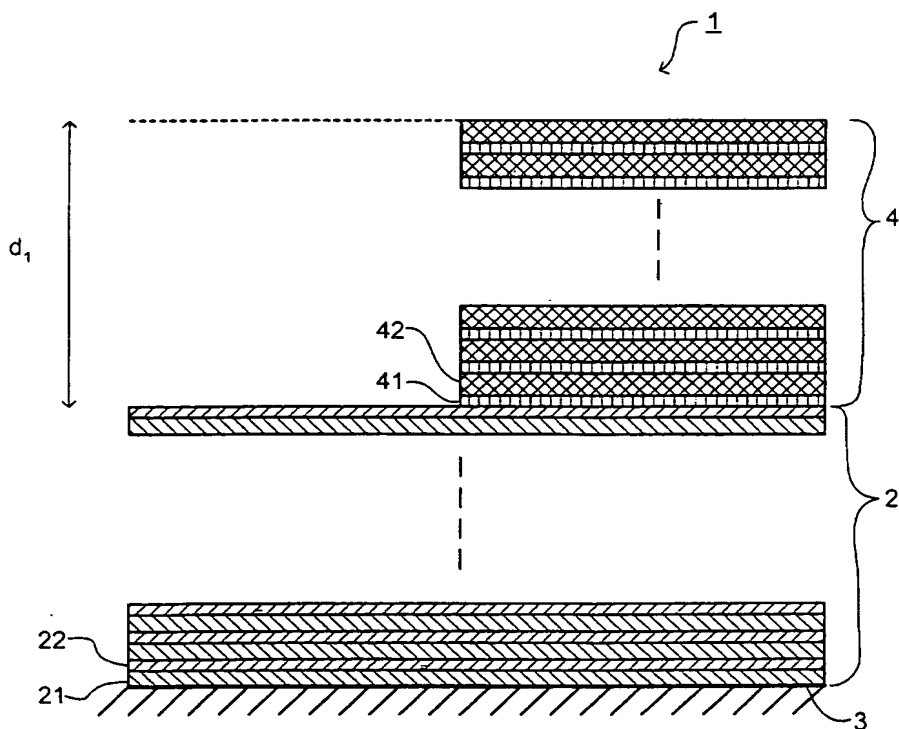
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(54) **Method of manufacturing a reflector, reflector manufactured thereby, phase shift mask and lithographic apparatus making use of them**

(57) A reflector for EUV has additional multi-layers on the front surface of a base multilayer stack provided selectively to compensate for figure errors in the base multilayer stack or the substrate on which the multilayer

stack is provided. A phase shift mask for EUV uses two multilayer stacks, one introducing a relatively phase shift and one introducing a relatively small phase shift, to for contrasting regions of the mask.

Fig. 2



Description

[0001] The present invention relates to a lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table for holding a substrate; and
- a projection system for projecting the patterned beam onto a target portion of the substrate.

[0002] The term "patterning means" as here employed should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.
- A programmable mirror array. An example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. The required matrix addressing can be performed using suitable electronic means. More information on such mirror arrays can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.
- A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

[0003] For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning means as hereabove set forth.

[0004] Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. comprising one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus — commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

[0005] In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual

layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

[0006] For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Twin stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, incorporated herein by reference.

[0007] In order to meet the continual demand of manufactures of semiconductor devices to be able to produce ever smaller features, it has been proposed to use Extreme Ultraviolet (EUV) radiation, e.g. with a wavelength of 5 to 20 nm, as the exposure radiation in a lithographic projection apparatus. Not least among the problems in designing such an apparatus is the creation of "optical" systems to illuminate evenly the patterning means and to project the image of the pattern defined by the patterning means accurately onto the substrate. Part of the difficulties in producing the necessary illumination and optical systems lies in the fact that no material suitable for making refractive optical elements at EUV wavelengths is presently known. Thus, the illumination and projection systems must be constructed out of mirrors which, at EUV wavelengths, have their own problems - specifically relatively low reflectivities and extremely high sensitivity to figure errors.

[0008] It is essential in a lithographic projection apparatus that the mirrors have high reflectivities since the illumination and projection systems may have a total of eight mirrors so that, with the additional reflection at the mask, the overall transmissivity of the systems is proportional to the ninth power of the reflectivity of the mirrors. To provide mirrors of sufficiently high reflectivity, it has been proposed to use mirrors formed by multilayer stacks of materials such as Mo, Si, Rh, Ru, RbCl, Sr and Be. Further details of such multilayer stacks are given in European Patent Applications EP-A-1 065 532 and EP-A-1 065 568, which documents are hereby incorporated herein by reference.

[0009] Projection systems using mirrors are particularly sensitive to figure errors at EUV wavelengths because a figure error of only 3nm would give rise to an error in the wavefront of about π radians, leading to destructive interference and making the reflector totally useless for imaging. Figure errors may have a variety of causes: errors in the surface of the substrate on which the multilayers are deposited, defects in the multilayers, stresses in the multilayer resulting from the manufacturing process, etc.. To correct such phase errors, it is proposed in WO97/33203 to add selectively an additional layer of crystalline or amorphous Si to the front surface of a reflector formed by a multilayer stack of Mo/Si. However, An additional layer locally reduces the reflectivity of the mirror, which may cause non-uniform illumination or exposure in lithographic projection apparatus.

[0010] It is an object of the present invention to provide improved reflectors useable with EUV radiation that have reduced figure errors and adequate reflectivity.

[0011] This and other objects are achieved according to the invention in a lithographic apparatus as specified in the opening paragraph, characterized in that at least one of the radiation and projection systems comprises a reflector provided With a multilayer stack comprising a plurality of base periods and at least one additional period covering only part of the effective area of said reflector to effect a local phase correction, different than a phase change on reflection from said base periods

[0012] By providing additional layers on top of the existing multilayer, desired phase corrections to compensate for the effects of figure errors in the multilayer or underlying substrate can be effected with a smaller effect on reflectivity. With the invention, it is possible to correct both "valley-like" (a local depression in the multilayer, e.g. caused by a depression in the substrate) and "hill-like" (a local projection in the multilayer) figure errors. The additional layers are provided in a pattern that is the negative of the figure errors, i.e. additional layers are provided in the valley of a valley-like figure error and additional layers are substantially provided around but not over the hill-like figure error.

[0013] The additional layers may be made of the same materials as the underlying multilayer stack, e.g. Mo/Si, or different materials, e.g. Mo/Y, Ru/Si or Ru-Mo/Si on an Mo/Si stack. Preferably, the thicknesses of said additional layers are optimized to provide an appropriate trade-off between phase shift to extreme ultraviolet radiation as compared to a vacuum layer of thickness equal to the total thickness of said additional layers, and total reflectivity.

[0014] According to a further aspect of the invention there is provided a device manufacturing method comprising

the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,

characterized by the step of:

- directing radiation in said projection beam or said patterned beam using a reflector provided with a multilayer stack comprising a plurality of base periods and at least one additional period covering only part of the effective area of said reflector to effect a local phase correction, different than a phase change on reflection from said base periods.

[0015] Further, the invention provides a method of manufacturing a reflector for use in the radiation or illumination systems of a lithographic projection apparatus, the method comprising the steps of:

- providing a multilayer stack on a substrate;
- determining any figure errors in the multilayer stack or substrate;
- selectively providing additional layers on the front surface of said multilayer stack to effect phase differences in radiation reflected by said reflector to compensate for the effects of said figure errors.

[0016] Still further the invention provides a phase shift mask for use in lithographic projection, said mask comprising a multilayer stack comprising a plurality of base periods and a phase-shifting multilayer stack comprising at least one phase-shifting period covering only part of the effective area of said mask to effect a local phase shift, different than a phase change on reflection from said base periods.

[0017] Still further the invention provides a device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,

characterized in that;

said step of using patterning means comprises using a phase shift mask, said mask comprising a multilayer stack comprising a plurality of base periods and a phase-shifting multilayer stack comprising at least one phase-shifting period covering only part of the effective area of said mask to effect a local phase shift, different than a phase change on reflection from said base periods.

[0018] Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

[0019] In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (e.g. with a wavelength of 365, 248, 193, 157 or 126 nm) and EUV (extreme ultra-violet radiation, e.g. having a wavelength in the range 5-20 nm).

[0020] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which:

Figure 1 depicts a lithographic projection apparatus according to an embodiment of the invention;

Figure 2 illustrates a reflector used in the first embodiment of the invention;

Figure 3 is a graph of phase shift and reflectivity vs. total thickness for additional Mo/Si layers;

Figure 4 is a graph of phase shift vs. total thickness for additional layers of various different combinations of materials.

Figure 5 illustrates a phase shift mask according to a second embodiment of the invention; and

Figure 6 is a graph of phase shift vs. total thickness for two multilayer stacks used in the phase shift mask of the second embodiment.

[0021] In the Figures, corresponding reference symbols indicate corresponding parts.

Embodiment 1

[0022] Figure 1 schematically depicts a lithographic projection apparatus according to a particular embodiment of the invention. The apparatus comprises:

- a radiation system Ex, IL, for supplying a projection beam PB of radiation (e.g. EUV radiation). In this particular case, the radiation system also comprises a radiation source LA;
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL (e.g. a mirror group) for imaging an irradiated portion of the mask MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

[0023] As here depicted, the apparatus is of a reflective type (*i.e.* has a reflective mask). However, in general, it may also be of a transmissive type, for example (with a transmissive mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

[0024] The source LA (e.g. a laser-produced or discharge plasma source) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ -outer and σ -inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired intensity distribution in its cross-section.

[0025] It should be noted with regard to Figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and Claims encompass both of these scenarios.

[0026] The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having been selectively reflected by the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and interferometric measuring means IF), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

[0027] The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (*i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;
2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the y direction) with a speed v , so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

[0028] Figure 2 shows a reflector 1 used in the first embodiment of the invention. The reflector 1 comprises a multilayer stack 2, e.g. comprising alternating layers of Molybdenum 21 and Silicon 22, grown on a substrate 4. To correct figure

errors in the multilayer reflector, e.g. deriving from figure errors in the substrate 3 or from defects in the manufacture of the multilayer stack 2, additional multilayers 4 are added locally, as necessary to provide the desired correction. The additional multilayers 4 may be made of alternating layers 41, 42 of the same materials as the multilayer stack 2, e.g. Molybdenum and Silicon, but have their thicknesses, optimized for the desired phase change. Mathematical techniques for optimization of the various layer thicknesses as described in European Patent Applications EP-A-1 065 532 and EP-A-1 065 568 may be used. To determine the figure errors that are to be corrected, interferometric techniques can be used.

[0029] Figure 3 shows the phase change $\Delta\phi$ (open circles), in units of π radians, achievable for the addition of 1, 2, 3, 4, 5 or 10 periods of Mo/Si as well as resulting increases in reflectivity (open squares). The dashed line is a least squares fit to the phase change values. In the following description the notation x-y/z (with x optional) is used to describe a period of a multilayer stack where y, and optionally x, may be denoted as an absorbing material and z as a spacer material. In addition, for a multilayer with additional periods, the base period is enclosed in {} and the additional layers in (). In general, a multilayer is "tuned" if the total optical thickness (physical thickness multiplied by refractive index) of its period is equal to half the wavelength of the incident radiation, taking into account the angle of incidence as necessary.

[0030] As alternatives to the optimized Mo/Si layers, Ru can be used in place of or in addition to Mo and Y can be used in place of Si. Figure 4 shows the phase shift $\Delta\phi$, in units of π radians, achievable for the addition of 1 to 10 periods of Mo/Y (open triangles), Ru-Mo/Si (filled circles) and Rh/Si (open squares) to a fifty period Mo/Si multilayer. The results of Figure 3 for the addition of optimized Mo/Si layers (open circles) are also shown for comparison. Figure 4 shows that the use of Ru-Mo in place of Mo and Y in place of Si can provide greater phase changes (sensitivities) for the same physical thickness of additional layers. In the Ru-Mo/Si additional layers, the Ru and Mo layer thicknesses were fixed at 2nm but may of course be optimized as desired.

[0031] In calculating the number and/or materials of the additional layers, account must be taken of the consequence of the complex refractive index of materials in the EUV region that the phase change on reflection, e.g. at the interface between Mo or Ru and Si layers, deviates from π radians which is expected for the non-absorbing case. For an Mo/Si stack the deviation is about 0.02 π radians per period so that a ten-period optimized Mo/Si stack exhibits a 0.43 π phase shift, as compared to a 0.62 π phase shift that would be expected were there no absorption. It will be seen that the data in Figures 3 and 4 take this effect into account. Further, the values of phase changes of the additional multilayers are given with respect to a hypothetical "vacuum layer" of the same thickness as the added multilayers. The designs presented in Figures 3 and 4 include a final capping layer, whereas the designs of Table 1 denote, giving rise to a slight difference in presented values for comparable designs.

[0032] Table 1 below gives calculated phase sensitivities for various multilayer structures useable as additional layers in the invention. It will be seen by comparing designs 1 and 2 that the phase sensitivity per period $\Delta\epsilon$ increases from 0.043 π to 0.054 π as the Mo thickness is deliberately set to 4.0nm. Similarly, Ru/Si designs 3 and 4 exhibit a large change in $\Delta\epsilon$ as the Ru thickness is increased from 1.98nm to 3.50nm. This is because of the lower n of Ru compared to Mo but the higher extinction coefficient of Ru means that there is a significant drop in peak reflectivity. The three-component Ru-Mo/Si additional layers maintain high peak reflectivities even as the Ru and Mo thicknesses are increased, with designs 6 and 7 exhibiting particularly high values of $\Delta\epsilon$. The yttrium-based stacks exhibit the greatest phase sensitivity due to the significant contribution of Y to the phase change with respect to vacuum.

[0033] It will also be seen that only small phase sensitivities are exhibited by the Rh/Si, Pd/Si and Pt/Si designs. This means that even a large physical thickness of such additional layers may be deposited yielding a negligible wavefront phase change (with respect to a hypothetical vacuum layer of the same thickness) and such layers may be optionally used as filler layers between the localized additional layers so that the reflector surface is substantially uniform. Note that in designs 13 and 14, the total (optical) thickness of the multilayer structure has been detuned to shift the peak reflectivity to 13.5nm (though the peak reflectivity quoted is at 13.4 nm) to increase the phase change sensitivity by changing the spacer thickness (Y or Si) with respect to designs 12 and 7, respectively.

[0034] Any figure error may be corrected by adding additional multilayers at those locations that exhibit a "valley"-like figure error. Another approach is to add the additional multilayers over the whole of the reflective surface and will away some or all of the added multilayers, as required, at those locations that exhibit a "hill"-like figure error. Filler stacks presenting a small or negligible phase change (as will be described in embodiment 2) may be added in between the additional multilayers presenting a large phase change to and-up-with an approximately level reflective surface.

Table 1:

| Phase sensitivity and effective peak reflectivity of various multilayer period structures grown on an optimized 50-period Mo/Si (2.77nm Mo and 4.08nm Si) base multilayer tuned for $\lambda = 13.4$ nm operation at normal incidence with a peak reflectivity of | | | | | | | |
|---|-----------------------------|----------------------|------|------|-------------------|------------|--------------------------------------|
| | ML period of the form x-y/z | Layer thickness (nm) | | | Peak Reflectivity | | $\Delta\epsilon$ (π radians) |
| | | x | y | z | 5 periods | 10 periods | |
| 1 | Mo/Si | - | 2.68 | 4.17 | 0.749 | 0.749 | 0.043 |
| 2 | Mo/Si | - | 4.00 | 2.90 | 0.725 | 0.716 | 0.054 |
| 3 | Ru/Si | - | 1.98 | 4.82 | 0.727 | 0.716 | 0.028 |
| 4 | Ru/Si | - | 3.50 | 3.40 | 0.678 | 0.658 | 0.080 |
| 5 | Ru-Mo/Si | 1.00 | 1.68 | 4.18 | 0.752 | 0.754 | 0.045 |
| 6 | Ru-Mo/Si | 1.80 | 1.80 | 3.30 | 0.737 | 0.734 | 0.073 |
| 7 | Ru-Mo/Si | 2.00 | 2.00 | 2.93 | 0.723 | 0.715 | 0.090 |
| 8 | Rh/Si | - | 1.51 | 5.25 | 0.704 | 0.679 | 0.015 |
| 9 | Pd/Si | - | 1.15 | 5.59 | 0.688 | 0.648 | 0.008 |
| 10 | Pt/Si | - | 0.87 | 5.85 | 0.678 | 0.625 | 0.003 |
| 11 | Mo/Y | - | 2.61 | 4.37 | 0.695 | 0.664 | 0.090 |
| 12 | Ru-Mo/Y | 2.00 | 2.00 | 3.06 | 0.685 | 0.639 | 1.109 |
| 13 | Ru-Mo/Y | 2.00 | 2.00 | 3.15 | 0.670 | 0.626 | 0.121 |
| 14 | Ru-Mo/Si | 2.00 | 2.00 | 3.10 | 0.658 | 0.608 | 0.111 |
| 0.748. | | | | | | | |

[0035] The second embodiment of the present invention provides a phase shift mask for use at EUV wavelengths. The phase shift mask can be used in a lithographic apparatus as described with reference to Figure 1, with or without the corrected reflectors described above.

[0036] A phase shift reflective mask 50 is shown in Figure 5 of the accompanying drawings. This comprises a base multilayer stack 51 each period of which comprises a layer of absorbing material 51a and a layer of a spacer material 51b. On top of the base multilayer 51 are selectively provided a phase shifting stack 52, again each period of which comprises a layer of absorbing material 52a and a layer of a spacer material 52b, and a filler stack 53, each period of which also comprises a layer of absorbing material 53a and a layer of a spacer material 53b. The phase shifting stack 52 and filler stack 53 are arranged in a-pattern as necessary to pattern the projection beam to cause the desired image to be projected onto the substrate. Design rules for the phase shift mask of the present invention can be adapted as necessary from those employed for phase shift masks at other frequencies.

[0037] The phase shift mask of the present embodiment exploits the ability described above to provide multilayer stacks with both large phase sensitivities and small phase sensitivities. A phase shift mask necessitates selectively shifting the optical wavefront by, for instance, π radians. A π radian (or any other value such as $\pi/2$) phase change is readily achievable with respect to a "vacuum layer" or with respect to a filler multilayer (e.g. designs 9 and 10 in table 1), albeit at the expense of some reflectivity. As shown in Figure 6, a π phase shift is shown between the a phase shifting stack 52 of Ru-Mo/Si (design 7 in table 1) and a filler stack of Pd/Si (design 9 in table 1) after approximately 11 periods. An advantage of such a phase shift mask with a π -radian phase change with respect to a filler stack is that the surface of the mask may be level to within ~ 3 nm.

[0038] Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention. In particular, the calculations on which the present examples are based employed the optical constants set out in table 2 below. To design reflectors and masks for use at other wavelengths, or should such constants be determined to be inaccurate, the skilled person can effect appropriate corrections.

Table 2:

Optical constants of the materials referred to above, The complex refractive indices ($n - ik$) are taken from: B.L. Henke, E.M. Gullikson, and J.C. Davis, "X-ray interactions: photoabsorption, scattering, transmission and reflection at $E = 50\text{-}30,000$ eV, $Z = 1\text{-}92$," At, Data Nucl. Data Tables 54, 181-342 (1993).

| Material | Optical constants ($\lambda = 13.4$ nm) | |
|----------|--|--------|
| | n | k |
| Mo | 0.9227 | 0.0062 |
| Pd | 0.8780 | 0.0443 |
| Pt | 0.8928 | 0.0577 |
| Rh | 0.8775 | 0.0296 |
| Ru | 0.8898 | 0.0165 |
| Si | 0.9999 | 0.0018 |
| Y | 0.9742 | 0.0023 |

Claims

1. A lithographic projection apparatus comprising:

- a radiation system for providing a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table for holding a substrate;
- a projection system for projecting the patterned beam onto a target portion of the substrate,

characterized in that:

- at least one of the radiation and projection systems comprises a reflector provided with a multilayer stack comprising a plurality of base periods and at least one additional period covering only part of the effective area of said reflector to effect a local phase correction, different than a phase change on reflection from said base periods
2. An apparatus according to claim 1 wherein the or each additional period is grown or deposited to cover substantially all the effective area of said reflector and selectively milled away to uncover said base periods.
 3. An apparatus according to claim 1 wherein the or each additional period is selectively grown or deposited after completion of said base periods.
 4. An apparatus according to claim 1, 2 or 3 wherein said additional periods are formed of the same materials as said base periods.
 5. An apparatus according to claim 4 wherein the or each additional period and said base periods comprise alternating layers of Mo and Si.
 6. An apparatus according to claim 1, 2 or 3 wherein the or at least some of said additional periods are formed of materials different than the materials of said base periods.
 7. An apparatus according to claim 6 wherein the or each additional period comprises a first layer of a first material selected from the group comprising Mo and Ru and a second layer of a second material selected from the group comprising Si and Y.
 8. An apparatus according to claim 7 wherein the or each additional period comprises three layers formed of Ru, Mo and Si respectively.

9. An apparatus according to any one of the preceding claims wherein the or each additional period has a different partition ratio than said base periods.

10. An apparatus according to any one of the preceding claims wherein the or each additional layer has a peak reflectivity at a wavelength different than the wavelength of said projection beam.

11. An apparatus according to any one of the preceding claims further comprising at least one filler layer provided on said base periods where said additional period(s) is not provided, said filler layer effecting a smaller phase shift than said additional period(s).

12. An apparatus according to any one of the preceding claims wherein said radiation system is adapted to provide a projection beam of radiation having wavelengths in the range of from 5 to 20nm and said reflector has a reflectance peak encompassing the wavelength of said radiation of said projection beam.

13. An apparatus according to any one of the preceding claims, wherein the support structure comprises a mask table for holding a mask.

14. An apparatus according to any one of the preceding claims, wherein the radiation system comprises a radiation source.

15. A device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,

characterized by the step of;

directing radiation in said projection beam or said patterned beam using a reflector provided with a multilayer stack comprising a plurality of base periods and at least one additional period covering only part of the effective area of said reflector to effect a local phase correction, different than a phase change on reflection from said base periods.

16. A device manufactured according to the method of Claim 15.

17. A method of manufacturing a reflector for use in the radiation or illumination systems of a lithographic projection apparatus, the method comprising the steps of:

providing a multilayer stack on a substrate;
determining any figure errors in the multilayer stack or substrate;
selectively providing additional layers on the front surface of said multilayer stack to effect phase differences in radiation reflected by said reflector to compensate for the effects of said figure errors.

18. A reflector manufactured according to the method of claim 17.

19. A phase shift mask for use in lithographic projection, said mask comprising a multilayer stack comprising a plurality of base periods and a phase-shifting multilayer stack comprising at least one phase-shifting period covering only part of the effective area of said mask to effect a local phase shift, different than a phase change on reflection from said base periods.

20. A phase shift mask according to claim 19 further comprising a filler multilayer stack comprising at least one filler period provided in the regions of said mask where there is no phase-shifting multilayer, said filler multilayer stack effecting a smaller phase shift than said phase-shifting multilayer stack such that said local phase shift is defined relative to the phase shift effected by said filler material.

21. A phase shift mask according to claim 19 or 20 wherein said local phase shift is substantially π radians at a wavelength in the range of from 5 to 20nm.

22. A device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,

characterized in that;

said step of using patterning means comprises using a phase shift mask, said mask comprising a multilayer stack comprising a plurality of base periods and a phase-shifting multilayer stack comprising at least one phase-shifting period covering only part of the effective area of said mask to effect a local phase shift, different than a phase change on reflection from said base periods.

23. A device manufactured according to the method of Claim 22.

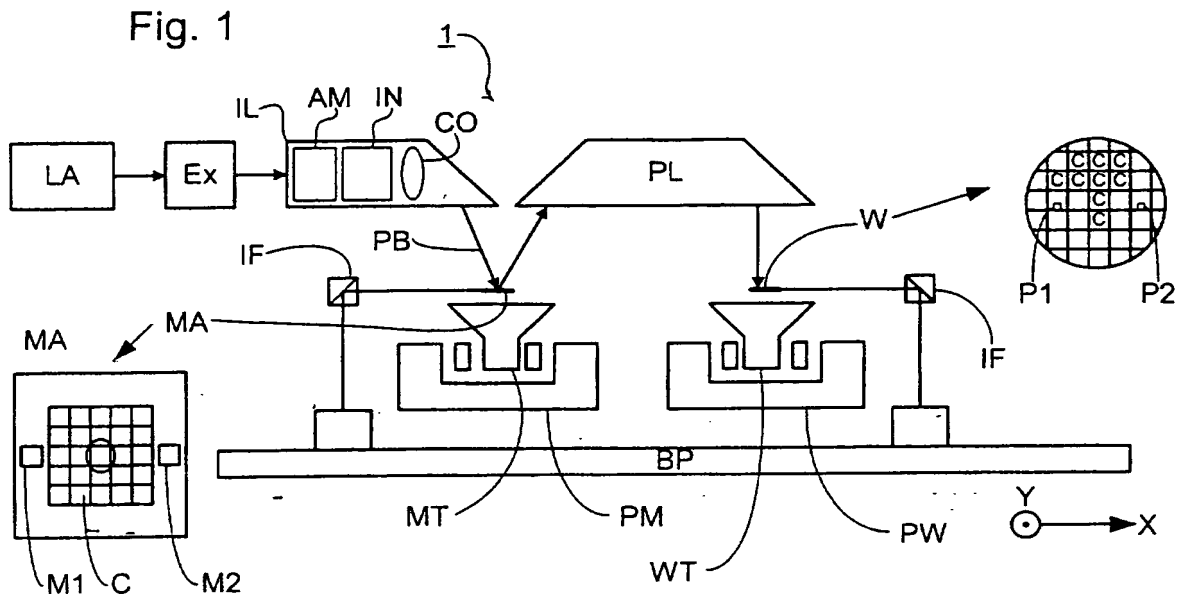


Fig. 2

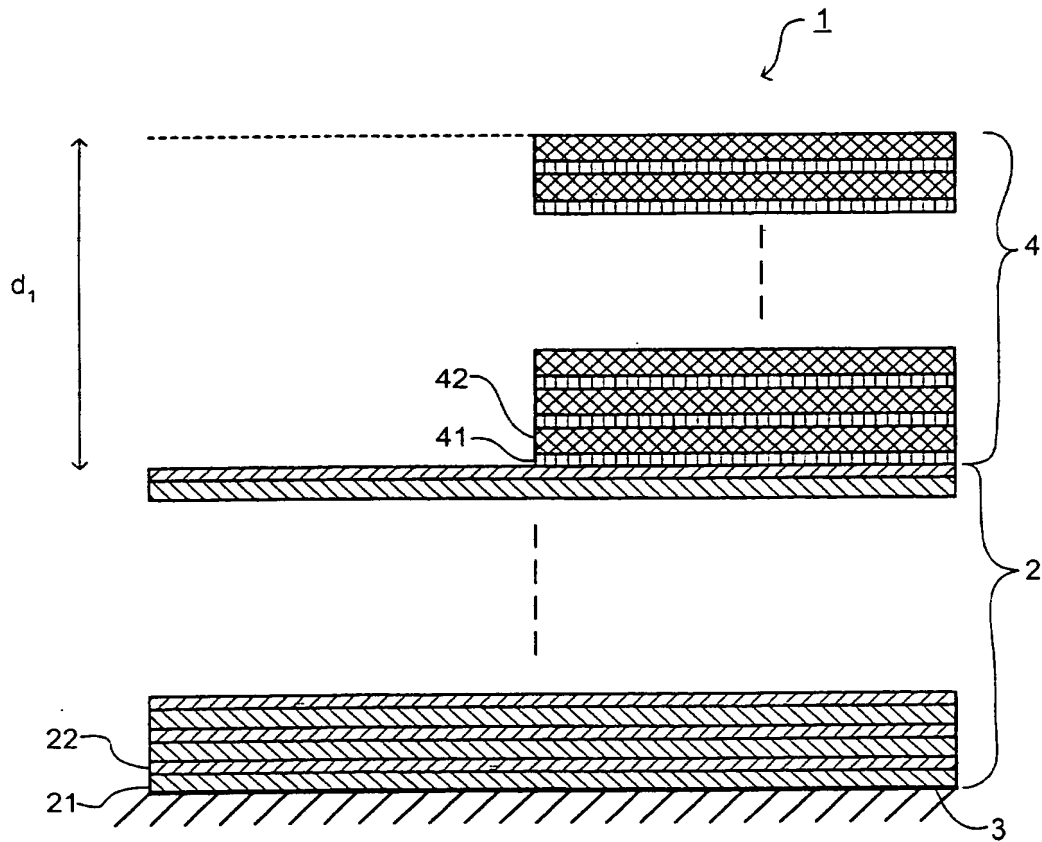


Fig. 3

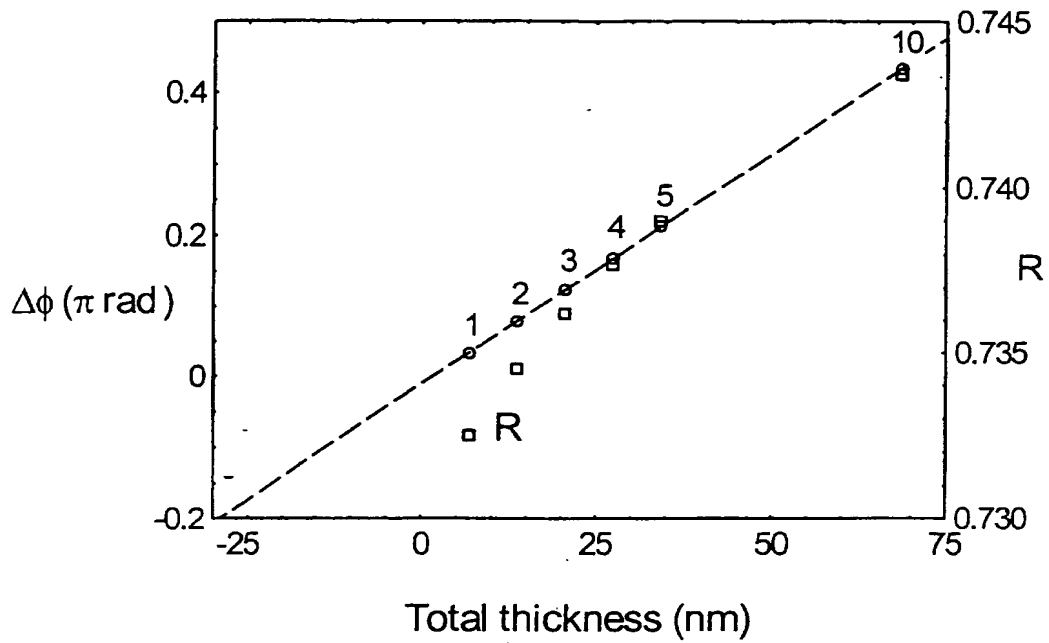


Fig. 4

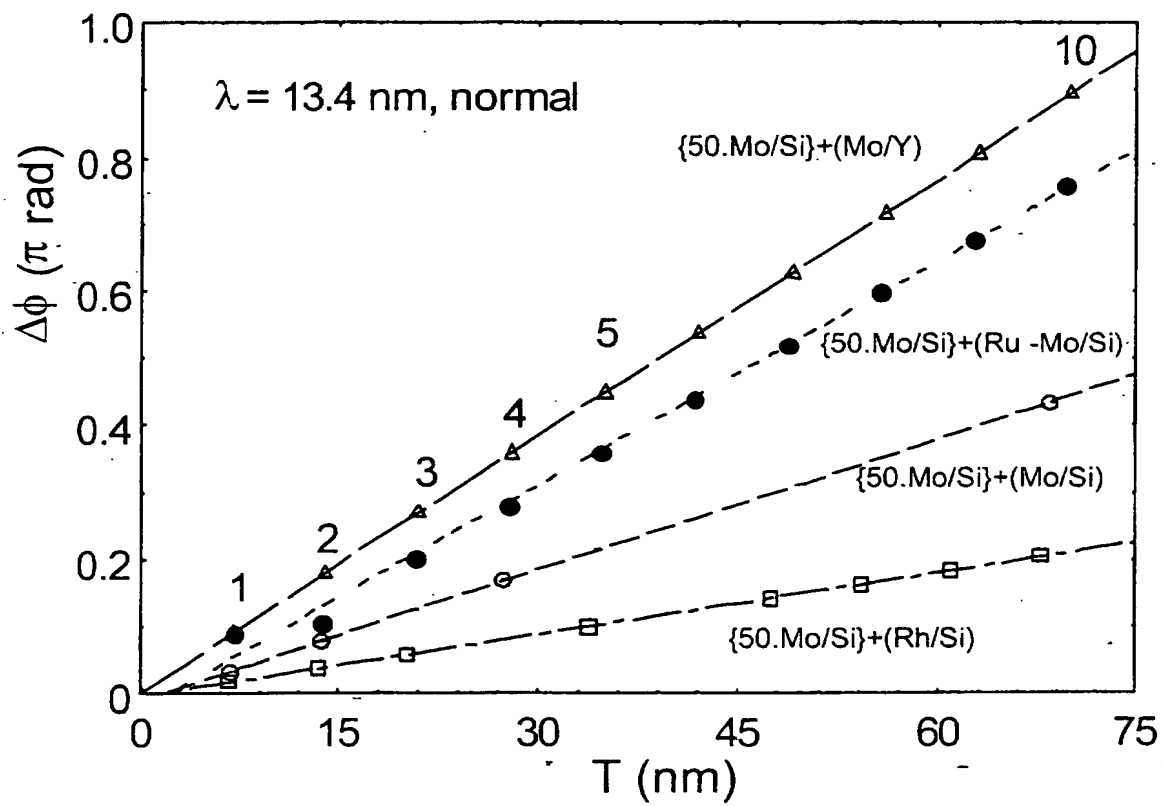


Fig. 5

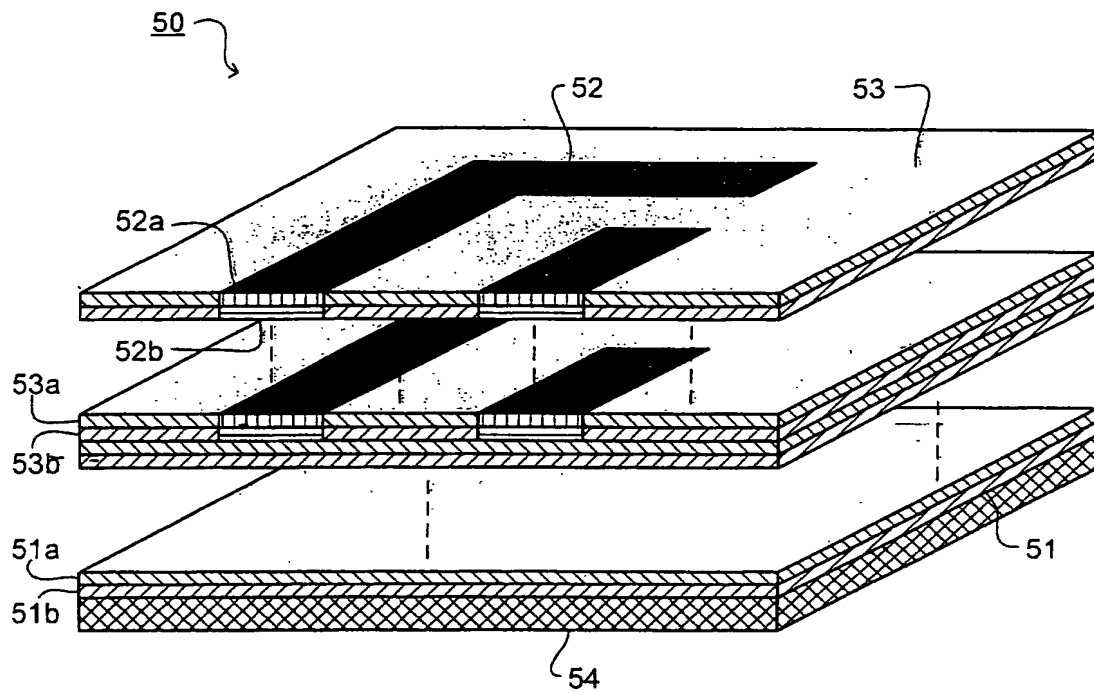
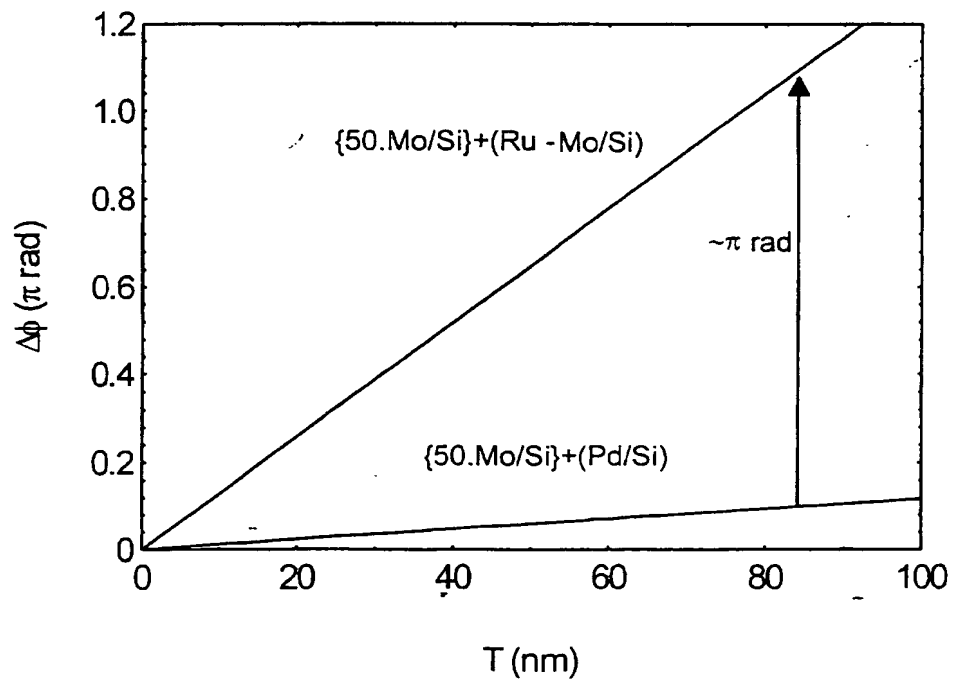


Fig. 6





European Patent
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Application Number
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| Place of search THE HAGUE | | Date of completion of the search 16 November 2001 | Examiner Haenisch, U |
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